

**Testimony of Dr. Carl Wieman
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My main points are simple.

- 1) Undergraduate science education is based on an obsolete model and is doing a poor job at providing the education that is needed today.
- 2) We now know how to fix it.
- 3) Until it is fixed, you can't fix K-12 science education.

Let me explain the basis of these claims.

There is a relatively recent phenomenon that a number of people like myself are doing education research within the science disciplines like physics, particularly at the college level. This scientific approach to science education provides a growing body of evidence showing that the great majority of college students (both science majors and non-science majors) are not gaining worthwhile understanding from their science classes. This research utilizes the improved understanding of how people think and learn coming out of cognitive science and educational psychology, and applies this understanding to the specific situations of individual college science courses. By studying the mental characteristics of expert scientists and those of novice students we are able to better delineate the desired outcome of science education and then measure how well different instructional practices affect students' thinking and understanding to achieve this outcome. The data show that most students are learning that science is boring and is little more than useless memorization of facts that are quickly forgotten after the exam. Our methods are different than those of Elaine Seymour, but some of our research indicates a similar conclusion to hers. Namely, science majors are not being created in college through educating students as to the utility and intellectual challenges and rewards of science. Instead, successful science majors are primarily those few students that, because of some unusual predisposition rather than special ability to do science, manage to survive their undergraduate science instruction.

Modern society has very different needs for undergraduate science education than in the distant past when our current instructional approaches were developed. Then the goal of college science education was primarily to train only the tiny fraction of the population that was preselected to become the next generation of scientists. Now we need to educate a far larger and more diverse student population to become scientifically literate citizens and the technically skilled work force required for a modern economy to thrive. This new, broader educational need does not eliminate the need to educate future generations of scientists. However, all the data suggests that improving science education for all students is likely to produce more and better-educated scientists and engineers as well.

The same science education research that shows the dismal results produced by the standard traditional college science classes are also showing us how to improve this situation. Experimental teaching methods have been developed that achieve much better learning and attitudes about science for most students. These methods recognize that it is not sufficient to follow the traditional practice of simply presenting the material as it is understood and appreciated by expert scientists. This just overloads the students' cognitive processing

capabilities and is perceived in a very different way than is intended. Research shows that effective science instruction recognizes the gap between the initial thinking of the student and that of the expert and provides structure and feedback to guide the student to actively construct their own “expert-like” understanding. This understanding must be based on the foundation of their prior thinking, which may be wrong, and hence must be explicitly examined and adequately addressed. Desirable features of instruction include presentation of ideas, homework, and exam problems in a form that has some obvious real-world connection and utility rather than as mere abstractions, and making reasoning, sense-making, and reflection explicit parts of all aspects of the course. Inherent in this more effective research-based instruction is the need to assess the individual student’s background and thinking and provide effective feedback and guidance. This would not have been practical to do on a widespread basis in the past, but computer technology now makes this economically feasible. More research and development of this technology, particularly software, is still needed to fully utilize this potential, however.

Widely adopted, these instructional methods and technology would increase the pipeline of scientists, produce a more technically literate and skilled general public, and provide better trained K-12 teachers. I emphasize this latter point because our studies show that the future K-12 teachers are among the worst in their learning of science and math in college. Elementary education majors have by far the least expert beliefs about science of all the different populations of college students that my group has measured. We also found that in a typical class of graduating elementary education majors who had completed all their math and science requirements, 30% of the students thought that the continents float on the oceans, and virtually none of them were able to answer the question, “if it takes you 2 minutes to drive a mile, how fast are you going?”. These future teachers have to learn math and science better than this in college if they are to teach it decently! That is why I claim that unless you improve science education at the college level first, you are wasting your time and money on trying to make major improvements in K-12.

So why haven’t colleges changed undergraduate education so that their students learn science much better? They haven’t done it because, first, while there has never been a shortage of strongly held opinions, only recently has there been real data showing how badly the traditional science education was failing for most students and how it could be improved. Also, while enough research has been done to clearly establish the general problem and the characteristics of more effective approaches, this work does not cover all subjects and grade levels, and the results are not yet widely known throughout the science community. Ultimately, what is needed is research and development to establish the specifics of how to measure and achieve effective learning across the full range of college science courses for the full range of college student populations. That does not yet exist, although it is clear how to do it. The second reason colleges have not yet changed is that the computer technology required for widespread implementation of these new teaching methods also did not exist until recently. Finally, and most important, there are no incentives to make such changes other than altruism. I spend a lot of time visiting and evaluating colleges and universities, and I can assure you that their financial support, prestige, and the tuition they can charge is quite unrelated to what their students are actually learning in science. Making the necessary educational changes, while inexpensive compared to the total spent on either K-12 or higher education, will require significant investments of money and effort. With budgets so tight, particularly at public Universities, no

one should be surprised that science faculty and departments primarily invest their time and resources in trying to excel in areas for which success is recognized and rewarded.

So how can one bring about this desired and attainable improvement in undergraduate science education?

I would argue that the first priority needs to be incentives to change education at the departmental level of the large research universities. These research universities set the standards for undergraduate science education in the US and train nearly all the college science teachers. The department is the unit for science education and to have sustained change, departments as a whole must change how they approach science education.

Virtually none of the federal support for improving college science education addresses the issue at this crucial level. The limited support available is typically spent on short term projects that involve one or two people per department spread out across as many institutions as possible. This is a politically attractive approach and these programs have had some excellent results, but they are doomed to largely remain localized and short-term, because they ignore organizational realities. They are the equivalent of trying to change the direction that a stream flows by scooping out a few buckets of water and pouring it in a different direction.

In summary, enough is known about how college students learn science and how to measure and achieve that learning so that undergraduate science education can be dramatically improved for all students. However that is not going to happen until colleges, particularly the large research universities, have incentives to make the investment required to bring about this change.

Carl Wieman grew up in the forests of Oregon and received his B.S. from the Massachusetts Institute of Technology in 1973 and his Ph.D. from Stanford University in 1977. He has been at the University of Colorado since 1984 where he holds the titles of Distinguished Professor of Physics, Presidential Teaching Scholar, and Fellow of JILA. He has carried out research in a variety of areas of atomic physics and laser spectroscopy, including using laser light to cool atoms. His research has been recognized with numerous awards including the Nobel Prize in Physics in 2001 for the creation of Bose-Einstein condensation in a vapor. He has worked on a variety of research and innovations in teaching physics to a broad range of students, including the Physics Education Technology Project, (<http://www.colorado.edu/physics/phet>) that creates educational online interactive simulations. He is a 2001 recipient of the National Science Foundation's Distinguished Teaching Scholar Award and the Carnegie Foundation's 2004 US University Professor of the Year Award. He is a member of the National Academy of Sciences and chairs the Academy Board on Science Education.